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SENSITIVITY OF THERMAL POWER GENERATION TO CLIMATE CHANGE

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Introduction

Climate change will have a wide range of impacts on the electricity industry affecting generation, transmission and demand. One specific effect will be that higher temperatures will tend to reduce the efficiency of thermal power stations, of particular interest in the United Kingdom (UK) given its overwhelming reliance on thermal technologies. Heat engine performance is fundamentally driven by the temperatures of the hot source and the cold sink to which heat is rejected. The Carnot efficiency is the maximum attainable efficiency. Whilst small increases in ambient temperature have a modest impact on Carnot efficiency, since real thermodynamic cycles are inherently less efficient, there is potential for power stations to show greater sensitivity to changes in ambient conditions driven by climate change. A reduction in air density could also affect the operation of CCGT stations. With gas turbines designed to operate with constant volumetric airflow, the reduced density causes the mass flow to fall, consequently reducing the power of the gas turbine and the amount of heat generated in the heat recovery boiler (Kehlhofer *et al.*, 1999).

Plant models

Three different power stations were modeled in this study: Torness nuclear power station in East Lothian, Longannet coal-fired power station in Fife, and Rye House combined cycle gas turbine (CCGT) station in Hertfordshire. The results presented here are focused on the Rye House CCGT plant. Opened in 1993 by Scottish Power it has a capacity of 715 MW. The station possesses three 155 MW Siemens gas turbines capable of burning gas at 39 m^3/s. The hot exhaust gases from the gas turbines feed their own heat recovery boiler and produce superheated steam which drives a 250 MW Siemens turbine generator. The station is cooled by an air-cooled condenser. A thermodynamic model of the station has been created and used to analyze the effects of changes in ambient temperature on power and energy output.

UKCP09 Scenarios

This analysis uses the climate change projections, UKCP09 [1], published in 2009. These projections were created from ensemble runs of a number of climate models and provide information on common climate variables for seven thirty-year time periods from 2010 – 2099 under a range of greenhouse gas emissions levels. Because a number of models were used to derive the projections, a probability distribution is available for many of the variables under a specific time period/emissions scenario. The spatial resolution of the output from the UKCP09 model is 25km. To aid interpretation, for the CCGT plant which takes air temperature as input, three emissions scenarios of ‘low’, ‘med’ and ‘high’ are shown here for three time periods: 2020s, 2050s and 2080s. While 2080 is well outside the planning range for power systems it has been included for completeness. Three probability levels have been discussed for each scenario in order to consider the range of possible outcomes: 10%, 50% and 90%.

Results

The mean air temperature changes applicable to the Rye House CCGT were taken for the closest grid cell. These changes were applied on a monthly mean basis to a baseline calculated from observed temperature data interpolated onto the same 25km grid as the projections[2]. The UKCP09 scenarios imply annual average air temperature rises of between 1-4ºC by the 2050s under medium emissions. This masks some more significant seasonal differences, with summer and autumn largely showing greater changes than winter and spring. The impact of this on power generation at the Rye House CCGT plant has been modelled and the changes in monthly mean power output calculated. The percentage changes for the 2050s under medium emissions appear to be worse in summer months, the maximum change being a drop of just over 3% in August at the 90% level. Additionally, the number of hours in each month have been used to derive the theoretical energy output for the year under the different scenarios – this assumes the station is running continuously as baseload – which gives some insight into the potential economic impacts that could be felt by the operators. The changes in annual energy output are shown for 2020s/'low', 2050s/'med' and 2080s/'high' scenarios at 10%, 50% and 90% probability in Figure 1. Examining the 2050s/'med' scenario, this reveals a very likely drop in annual energy output of 1%, with a 10% chance that it could be as much as 2.3%.

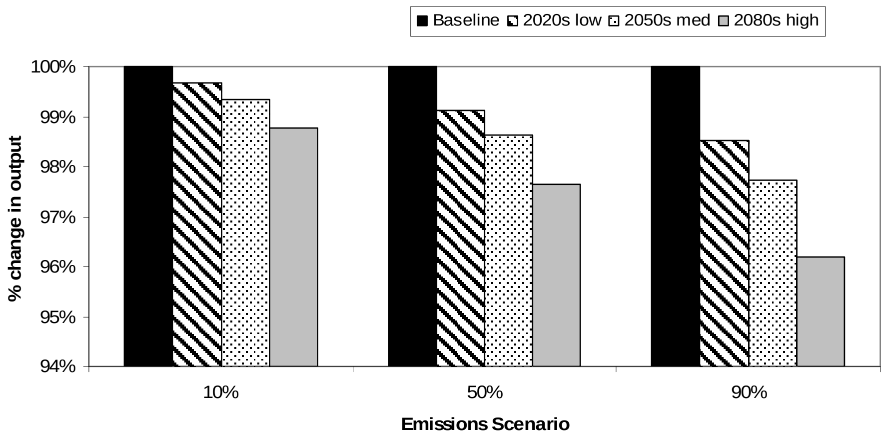

Figure 1: Change in annual energy output for range of time/emissions/probability scenarios (%)

Discussion

The changes projected by this model are not large in magnitude, but have the potential to cause disruption in cases of peak load, particularly when combined with a possible shift to in the demand peak to summer months. The fact that the reduction in power appears to be worst in summer could prove to have a significant impact. The economic consequences of the calculated drop in yearly energy output are difficult to judge without consideration of other circumstances, but again, the seasonal impacts could be amplified.

References

Kehlhofer RH, Warner J, Nielsen H, Bachmann R. Combined cycle gas-steam turbine power plants, Ed. Pennwell, USA; 1999. p. 288
